WITH COMPLIMENTS OF THE AUTHOR

ICE ON CANADIAN LAKES

BY

J. B. TYRRELL

M.A., M. INST.M.M., F.G.S., ETC.

Late of the Geological Survey of Canada.

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By J. B. Tyrrell, M.A., F.G.S., &c.

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Last week your president, in his address, complained that he had been under the necessity of delivering two presidential addresses in two consecutiveyears, but he is in an exceedingly comfortable condition compared to the one that I find myself in, for in looking over the list of six lectures to be delivered in this hall before next New Year, I see that five are by professors whose business i. is to talk impressively and accurately for three or four hours a day and to whom an extra hour, more or less, is mere added enjoyment, while I am placed in the middle of this list of talkers and am expected to compete with them on even terms though my business is to work and keep silence, for if I should say a word about any mine that I had examined my reputation would be gone for ever.

Though mining is the most interesting subject to me and probably one of the most interesting to the people of Ontario, as it is certainly one of the most important to them, nevertheless we will step aside for a little while and consider a subject that might occupy our attention profitably and enjoyably through the coming winter.

Most of us in Canada have opportunities for observing the formation and character of the ice which covers our lakes during the winter, for though Lake Ontario, on the shore of which we in Toronto live, is never entirely covered with a coat of ice, Toronto Bay, which is a small and almost isolated lake in itself, does freeze over, and the thousands of lakes, large and small, scattered throughout Northern Canada, which are occasionally visited by many of us, are covered every winter with solid ice from shore to shore.

It will be interesting for us to attempt to follow the method of formation of this ice and any changes that may occur in it from time to time from the beginning of winter until the bright sunshine of the long spring days breaks it up and dissolves it into water again.

First let us understand that ice is much lighter than water and floats with great buoyancy on its surface. A cubic foot of water at 32°F. weighs

62.4 lbs., while a cubic foot of ice at approximately the same temperature weighs 57.2 lbs. A cubic foot of ice will, therefore, float with its upper surface an inch above the water and will support a weight of 5.2 lbs. before it sinks, and a square foot of ice an inch thick will support a weight of .43 lbs. Like other solids, it contracts with decrease of temperature, the linear coefficient of expansion varying from .00005 to .00002 or from 3-1/6 to 1-1/4 inches per mile for each degree F.

At the end of autumn as the days become rapidly shorter and colder with the approach of winter, the temperature of the water in the lakes gradually lowers until about the beginning of November it has fallen to freezing point and ice begins to form around the shores where the convection currents can carry the heat quickly up and down through the shallow water and the earth or stones at the bottom can be cooled by radiation into the air.

At the same time the moisture in the air, which, during the summer, periodically descends to the earth in the form of rain, now begins to fall in the form of snow, and as the snow falls into the lakes part of it remains unmelted in the cold water and adheres or freezes to the edge of the shore ice. Every cold day or night the shore ice becomes thicker by the freezing of additional particles to it from below, as the heat is abstracted from the water by conduction through the ice, and at the same time its edge extends farther and farther into the lake until it completely covers the water. In this way a smooth covering of ice may be formed over the lake. On the other hand a period of very cold weather may suddenly cause the formation of a sheet of ice several inches in thickness over the whole lake.

On some of the large lakes, just after they have been frozen over, one of the heavy storms, so common in the autumn and early winter, may arise, and the wind and waves may break the ice into irregular masses and fragments, drive them towards the shore, or pile them up against it. At the same time, however, some of the first-formed ice will remain frozen fast to the shore and form an efficient protection to it. Thus the fragments of ice broken up by the storms in the early part of the winter have very little influence in displacing the sand and boulders which compose the shore, though they may throw up tree-trunks and floating masses of timber high up over it.

These storms are often followed by cold, calm weather and during this cold spell the broken ice will be frozen into a rough, irregular covering. Such a rough refrozen sheet of ice may very often be found on many of the larger northern Canadian lakes.

When I crossed Lake Winnipeg in December, 1893, it had been frozen with a smooth surface, and had remained in that condition, so that we travelled over it in our dog-sleighs with ease and comfort; but when I travelled down the same lake in the following year it had evidently been frozen over early in the autumn, the ice had afterwards been broken up by a heavy storm and it had frozen again with the jagged points and edges of the masses of ice projecting in every direction, so that it was quite impossible for us to take a straight course over the ice as we had done in the previous year. In consequence of this we were obliged to keep to the shore and to follow all its bays and indentations, which made our journey very much longer and more arduous. The irregularities in the surface of the ice would in time be filled with the snow which had been constantly drifted over it, and it is quite likely that towards the end of winter the general surface would have been rendered flat and regular. In that case it might be impossible to say that the ice had not frozen quietly, except that it would be a foot or two thicker than usual and that it would not have its usual regular structure.

The Yukon River furnishes some of the best examples of rough ice to be seen on any of our inland waters. Every year after the ice freezes, parts of it break up again and the broken masses are carried down by the current and piled up against the smooth unbroken ice which remains here and there across the river. Thus an ice-jam, sometimes many miles in length, may be formed, and as this freezes into a solid mass it makes a very rough irregular surface over which it is difficult to travel with sleighs or even on foot. (See Plate VI.)

The old winter trail from Skagway to the Klondike used to run down the Yukon River. The smooth unbroken ice made an excellent road, but when the broken and refrozen ice was encountered it was found practically impossible to travel over it and it was often necessary to search out a trail through the woods on one side or the other of the river, perhaps for several miles at a time, in order to find some easy way around the rough ice.

The rains, common in the autumn, usually raise the water in the lakes and rivers to a high stage about the time that the severe cold of winter sets in, and that the ice begins to form. After the ice has formed and the winter has set in, almost all the moisture that falls on the surface of both the land and water falls as snow. A small portion of this snow evaporates into the air, but the greater portion of it remains and accumulates on the surface of the ground throughout the winter. It thus gives rise to a set of conditions which differ materially from those which prevail during the

summer, for in the latter season, though the forests and swamps n act as efficient reservoirs, the moisture which falls as rain runs off c tinuously and rapidly into the streams and lakes as soon as it falls, wl in the winter the moisture which falls as snow continues to pile up c after day and week after week, very little water soaks into the grou to supply springs, the surface run-off is almost entirely stopped, the sup of water flowing into the lakes is greatly reduced, and consequently level of the surface of the water in the lakes drops very consideral As the ice is floating on the surface of the water it necessarily falls water, except along the shallow shores where it was first formed and wh it is now frozen to and rests on the sand and gravel of the bottom.

If it were possible for the water to drain completely out of the la the ice which had first formed on them would then sag down and rest the bottom everywhere, but this is not possible, for the outlets of the la are sufficiently high to prevent the water from draining entirely out them, but, nevertheless, the ice sags down as much as the outlet of lake will permit and therefore it slopes downwards for a certain indefi distance from the shore towards the lake and then merges into the gen level ice which is floating on the water.

As I have already stated, most of the ice is floating on the wa and for a longer or shorter time, according to its thickness, its has bu ancy and strength enough to hold up the load of snow that falls on If snow falls to a considerable depth soon after the ice is first formed it press the ice down into the water, for an inch of ice will only carry ab five-sixths of an inch of dry snow, so if the ice is three inches thick it carry two and one-half inches of dry snow but no more. In such a c if the fall of snow has been greater than two and one-half inches it press the ice down and the water will rise up through air holes, fissu etc., and wet the under part of the snow. It is very well known to r living in the north that the ice on the lakes is certain to be wet, and t travel over them is unpleasant and even dangerous for a long tim there has been a very heavy fall of snow soon after the ice has first forn

A good illustration of these conditions was seen on Gowganda La where the ice had attained a thickness of about twelve inches. Tl had been a heavy fall of snow which had accumulated to a depth of f two to three feet in the surrounding forest, and as there had been little wind accompanying the snow, it might have seemed reasonabl look for a similar depth on the lake. But ice a foot thick will not sup the weight of two feet of dry snow, and consequently it had been pre down into the water, so that while it was completely covered to a de

of ten or twelve inches, from four to six inches of the lower part of the snow was soaked with water. Shortly after the snow storm very cold weather set in and this wet snow was frozen to ice, and thus the general thickness of the ice was greatly increased by freezing from above and not from below.

Later in the winter the weight of snow would again become too great for the buoyancy of the ice and would press it down into the water, which would rise through and over it and cover it, possibly to a depth of a foot or more, with watery slush. The surface of this slush might be again frozen during the spells of extremely cold weather which occur in the latter part of the winter. In this way two sheets of ice might be formed, separated by a foot or more of water and slush. These two thicknesses are very commonly found on our northern lakes in the latter part of the winter and a man or team of horses may break through the upper and still be supported by the lower layer. Instead of freezing and forming a second upper thickness of ice, the water may melt the snow and carry it off the surface or down again beneath the ice. Thus relieved of its load of snow and slush, the ice will again float to the surface and may become quite dry and hard. The formation of this dry, hard ice just at the approach of spring, after it has been very wet and sloppy for some weeks, is a condition that is well known to lumbermen and others who have occasion to travel in the north.

In regions where the snowfall is light, a sudden fall in the temperature of the air will have considerable effect in increasing the thickness of the ice. While the cold weather causes the ice to thicken, it also causes it to contract, for as stated above, ice has a fairly high coefficient of expansion, and a change of one degree F. in temperature causes it to expand or contract to the extent of about two or three inches in a mile. In extremely cold nights this contraction often causes extensive cracks or fissures, which are formed with the accompaniment of loud reports so that the booming of the ice, while these fissures are forming on the larger lakes in the north, can often be heard for many miles. The fissures usually cross a lake in the same place each year, probably between salient points on the shores, and give rise to lanes of open water. On Lake Winnipeg these stretches of open water often cause obstructions in the ice roads which are used in teaming from place to place over the lake.

Now as it is quite clear that these fissures are formed by the contraction of the ice with the lowering of the temperature it was reasonable to infer that the ice would expand again horizontally when its temperature was raised. The fissures formed by contraction freeze over quickly in the cold weather and as the temperature rises the ice expands and closes

these open lanes of water or even crushes the new ice which had formed in them, thus giving rise to ridges of ice where the open water was before.

But farther than closing these open lanes of water, the ice does not expand horizontally with the rise of temperature.

It has been argued by many, and even by as high authorities as Professor G. K. Gilbert, of the United States Geological Survey, and by Professors Chamberlin and Salisbury in their Geology, Vol. I., p. 371, that the ice expands with irresistible force and that it presses on the shores and shoves the gravel and sand, to which it freezes, back each year until it piles up walls of this gravel, sand and boulders around the shore. My attention was drawn to statements such as these more than twenty years ago and since that time I have spent many winters beside the frozen waters of our north country and have watched closely for evidence of the pushing of the ice towards the shore in winter, but have never been able to detect any evidence of such action. The shores remain perfectly undisturbed all winter except for the formation of the slope towards the water previously described, and if there is any change in the shore it would appear to be in the nature of a drag towards the water rather than in the opposite direction. Trees and boulders were seen lying just at the edge of the ice and no tendency was ever observed for the ice to move up toward them away from the lake. The ice was frozen too hard to the ground to permit of any shoreward movement.

That the ice must expand with almost irresistible force is unquestionable, but my observations have clearly shown me that, even with very rapid rises in temperature it does not expand horizontally, except to close the lanes of open water. If such horizontal movements did occur a rise of temperature of 50°F. would mean that the ice on Lake Temiskaming, which may be taken as a fairly typical example of our northern lakes, would expand thirty-five to fifty feet between its opposite shores, while between New Liskeard and Fort Temiskaming, a distance of eighteen miles, it would expand from one hundred and fifty to two hundred and twenty-five feet, instead of which it does not appear to expand at all, for it does not shove up on the shore during the winter. On Lake Winnipeg, which has a width of sixty-six miles and a length of two hundred and sixty miles, and which is frozen over completely every winter, a similar rise in temperature would cause an expansion of five hundred feet to eight hundred feet in the width of the ice, and two thousand to three thousand feet in its length, while the only evidence of this expansion consists in the closing of some few narrow lanes of open water. The expansion with increase of temperature must, therefore, be taken up by a vertical thickening of the

PLATE I.

Lane of water between the ice and the shore on Lake Temiskaming, May 6, 1909.

Lane of water between the ice and the shore at Haileybury on Lake Temiskaming, May 6, 1909.

PLATE II.

Lake Temiskaming covered with loose floating ice which has been shoved up on the shore by the wind. Logs and stones may be seen lying in front of the wall of ice. May 6th, 1909.

PLATE III.

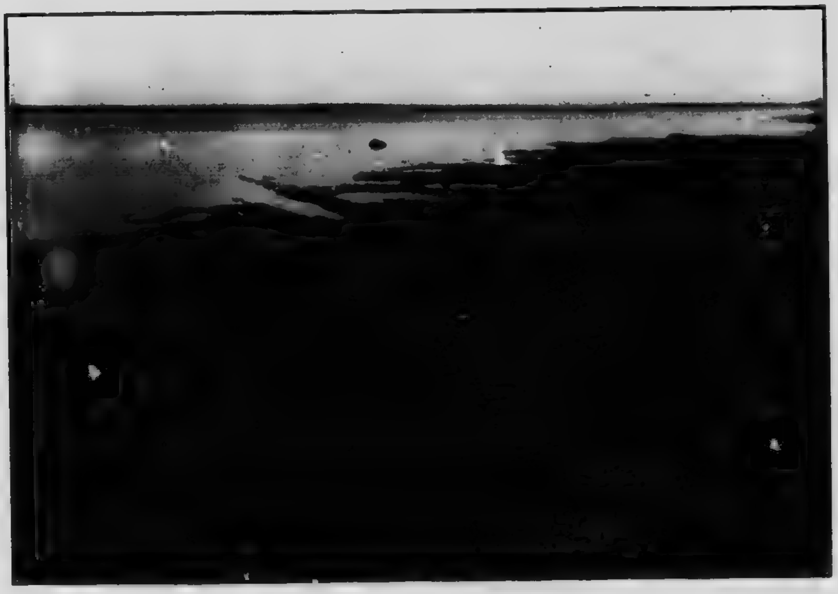
Lane of water between ice and shore on Dubawnt Lake, August 12th, 1893.

Shore of Aberdeen Lake, showing boulder wall and stones shoved up by loose ice, August, 1893.

PLATE IV.

Boulder on north shore of Lake Winnipegosis, which has been pushed to its present position by the loose ice on the lake in the spring. The upper picture is looking towards the lake, while the lower picture is looking towards the shore. On it a wall of boulders which have been pushed back by the loose ice is seen in the background.

PLATE V.



Boulders shoved up on shore of Lake Winnipegosis by loose ice.

Boulders shoved up on shore of Lake Winnipegosis by loose ice.

PLATE VI.

Rough ice on Yukon River at Dawson.

Rough ice on Yukon River below Selkirk.

ice, in other words, the viscosity of the ice must permit practically the whole of the expansion with increase of temperature to act vertically.

While the effect of horizontal expansion, if it occurred, would be very great, the influence of expansion vertically has very little effect in increasing the thickness of the ice.

Now as the spring approaches, and the weather becomes bright and warm, the ice begins to melt rapidly, at first around its edges close to the shore where the heat from the sun, and also the heat rising from the earth beneath the water, have the greatest combined effect. This melting of the ice along the shore in the early spring loosens it from the sand, gravel and rock so that it is no longer frozen tight to the beach, and consequently it cannot then press the materials forming the shore back by expansive force. The ice is then free from the shore, and is floating loosely on the water, while the snow is melting on the surrounding country, and is discharging a large quantity of water into the lake, which is rapidly rising in consequence. From that time onwards until it melts away, the floating ice is moved backwards and forwards on the surface of the water by the varying winds. One day with a south wind, it may be drifted on the north shore, while the next day the north wind may drive it with equal or greater force on the south shore, and while it is pressed against the southern shore there will be a lane of water between the ice and the land on the north shore and *vice versa*.

During the time in which the ice is driven backwards and forwards by the varying winds for days and even weeks before it finally breaks up and melts away, it is a very efficient instrument for ploughing up the beach, since the force with which it is driven against the shore is almost irresistible, and wherever it strikes against loose materials, such as sand, gravel or boulders, it drives them back, and often piles them in a wall behind the shelving beach.

Dubawnt Lake, one of the large bodies of water out in the Barren Lands of Northern Canada, is always more or less completely covered with ice. In August 1893, when I was travelling in canoes through a lane of water between the ice and the shore, the ice was sometimes several hundred feet away from the land and at other times was tight up against it. One night the ice was resting tight against the shore and we camped, intending to portage across a long point of land in the morning, but on the following morning, when we arose, the ice had withdrawn a hundred feet or so from the shore and we were able to paddle easily and comfortably around the point across which we had expected to have been obliged to

make a long and difficult portage. The shores of this and of many other lakes in the vicinity showed abundant evidence of the shoving and pounding of floating ice, and in fact such evidence may be seen on almost any of the Canadian lakes in the spring, before the waves, caused by the summer and autumn storms, have reassorted the loose material on the beaches.

The pictures of the shore of Lake Temiskaming at Haileybury show a lane of water between the ice and the land and a number of places where boulders and logs have been pushed up by the ice.

Some excellent examples of the work thus accomplished by the ice in the spring were seen on the wide flat shores of the lakes in the Province of Manitoba. On these shores shallow clay flats extend long distances out into the water and boulders are scattered here and there through the mud over them. As the loose ice was driven backwards and forwards over the lake it was often shoved up on these flats and it acted as a scraper and carried the larger stones and boulders on ahead of it.

The following remarks were made in 1887 and referred to the shore of Lake Winnipegosis, the second largest lake in Manitoba:—"In this protected bay, and especially on its north side, which is bordered by a fringe of rushes, are some of the best examples of ice-grooving that have ever come under the writers observation. Boulders are lying here and there, and most of them show signs of having been moved from three inches up to thirty-three paces. The sand and pebbles of the beach are generally piled up on their landward side, while a groove extends towards the lake. The majority of the shorter grooves on the north shore trend N. 60° to 75° W. One, ten paces long, trends N. 10° W., and in this the boulder is seen to have at first lain transversely to the direction of the groove, and to have been turned round and shoved with its greater axis along the groove. A group of six boulders have been shoved in a direction S. 70° W. Another boulder 44 x 45 x 22 inches has taken the following course, turning sharply at the changes of direction: From its starting place in the water N. 50° W. for fourteen feet six inches, then N. 25° W. ten feet eight inches to the stone. Another boulder is now lying in the water at the end of a straight groove about fifty feet long, running from it in a direction N. 35° W. towards the shore, and pebbles are piled up on its lakeward side, showing that it has been shoved out from the shore when the ice was carried out by the wind. The shore throughout this distance has a constant direction S. 50° W."

"The irregularity in length and direction of these grooves on a soft,

straight shore shows clearly that they are caused by the irregular pressure of broken ice in the spring, rather than by the regular expansion of the ice during the winter with the variations of the temperature."

"Behind this low beach is a wall of boulders that have been shoved back against the higher ground within the edge of the woods, and have reached their permanent resting place, where they can no longer be affected to any considerable extent by the waves and ice of the present lake. Within the woods is a ridge twenty feet high scattered with gneissoid boulders."*

The observations and conditions cited this evening establish the following points, viz.:

In regions of heavy snowfall the ice is being constantly pressed down into the water by the weight of the snow, and therefore there is often water over it and beneath the snow.

In these regions the ice increases in thickness mostly from the top, by the freezing of the overflowing water.

In regions of light snowfall it increases in thickness mostly from the bottom.

It contracts ~~expands~~ laterally with decrease in temperature, but most of the expansion with increase in temperature is vertical.

Throughout the winter, it remains firmly frozen to the shore, and quite immovable, except that it falls with the lowering of the water in the lakes.

In the spring it thaws first along the shore, and around any stones, etc., which attract the heat.

The loose ice floating on the water of the main body of the lake in spring is pushed against the shore by the wind, and sand and stones are shoved up by and in front of it.

These stones are often shoved in this way to the back of the beach and are there piled into rough and heavy walls or ramparts.

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* Report on North Western Manitoba by J. B. Tyrrell, An. Rep. Geol. Sur. Can Vol. 1890-1, pp. 64-5 E., Ottawa Govt. 1893.